NAVAL POSTGRADUATE SCHOOL

MONTEREY, CALIFORNIA

MBA PROFESSIONAL REPORT

Discrete-Event Simulation Modeling of the Repairable Inventory Process to Enhance the ARGCS Business Case Analysis

---

By: Alfred P. Bello III
Frankie Rios
Robert B. Carpenter

December 2006

Advisors: Kenneth H. Doerr
Raymond Frank
Keebom Kang

Approved for public release; distribution is unlimited.

THIS PAGE INTENTIONALLY LEFT BLANK

REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*	**2.REPORT DATE** December 2006	**3. REPORT TYPE AND DATES COVERED** MBA Professional Report

4. TITLE AND SUBTITLE: Discrete-Event Simulation Modeling of the Repairable Inventory Process to Enhance the ARGCS Business Case Analysis	**5. FUNDING NUMBERS**
6. AUTHOR(S) Alfred Bello, Frankie Rios, Robert Carpenter	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Naval Postgraduate School Monterey, CA 93943-5000	**8. PERFORMING ORGANIZATION REPORT NUMBER**
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) N/A	**10. SPONSORING / MONITORING AGENCY REPORT NUMBER**

11. SUPPLEMENTARY NOTES The views expressed in this report are those of the author(s) and do not reflect the official policy or position of the Department of Defense or the U.S. Government.

12a. DISTRIBUTION / AVAILABILITY STATEMENT Approved for public release; distribution is unlimited	**12b. DISTRIBUTION CODE** A

13. ABSTRACT (maximum 200 words)

The objective of this project was to identify and more accurately predict the maintenance and supply chain costs and savings related to the Agile Rapid Global Combat Support (ARGCS) system. The project focused on a portion of the ARGCS business case analysis (BCA) model developed by CDR David Crosby. CDR Crosby's BCA model listed various potential savings associated with ARGCS technologies that were difficult to quantify during his initial BCA research. The focus of this research was to determine the likely benefits and cost savings that ARGCS may have on maintenance and supply functions. Using pre-existing maintenance and supply data, a model was developed to more accurately determine any maintenance and supply related cost benefits. The only F/A-18 Weapons Replaceable Assemblies (WRA) that were analyzed during this research were those that will be tested during the summer 2007 Advanced Concept Technology Demonstration (ACTD) at NAS Lemoore. Results of the simulation indicate there is an expected increase in operational availability and several cost savings associated with the implementation of ARGCS technologies.

14. SUBJECT TERMS Advanced Concept Technology Demonstration; Agile Rapid Global Combat Support; Discrete-Event Simulation Modeling of the Repairable Inventory Process to Enhance the ARGCS Business Case Analysis	**15. NUMBER OF PAGES** 49
	16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT Unclassified	**18. SECURITY CLASSIFICATION OF THIS PAGE** Unclassified	**19. SECURITY CLASSIFICATION OF ABSTRACT** Unclassified	**20. LIMITATION OF ABSTRACT** UL

NSN 7540-01-280-5500 Standard Form 298 (Rev. 2-89) Prescribed by ANSI Std. 239-18

THIS PAGE INTENTIONALLY LEFT BLANK

Approved for public release; distribution is unlimited

DISCRETE-EVENT SIMULATION MODELING OF THE REPARABLE INVENTORY PROCESS TO ENHANCE THE ARGCS BUSINESS CASE ANALYSIS

Alfred P. Bello III, Major, United States Air Force
Frankie Rios, Lieutenant Commander, United States Navy
Robert B. Carpenter, Captain, United States Air Force

Submitted in partial fulfillment of the requirements for the degree of

MASTER OF BUSINESS ADMINISTRATION

from the

NAVAL POSTGRADUATE SCHOOL
December 2006

Authors: ______________________________
Alfred P. Bello III

____
Frankie Rios

____
Robert B. Carpenter

.

Approved by: ______________________________
Kenneth H. Doerr, Lead Advisor

____
Raymond E. Franck, Support Advisor

____
Keebom Kang, Support Advisor

____
Robert N. Beck, Dean
Graduate School of Business and Public Policy

THIS PAGE INTENTIONALLY LEFT BLANK

DISCRETE-EVENT SIMULATION MODELING OF THE REPAIRABLE INVENTORY PROCESS TO ENHANCE THE ARGCS BUSINESS CASE ANALYSIS

ABSTRACT

The objective of this project was to identify and more accurately predict the maintenance and supply chain costs and savings related to the Agile Rapid Global Combat Support (ARGCS) system. The project focused on a portion of the ARGCS business case analysis (BCA) model developed by CDR David Crosby. CDR Crosby's BCA model listed various potential savings associated with ARGCS technologies that were difficult to quantify during his initial BCA research. The focus of this research was to determine the likely benefits, and/or cost savings that ARGCS may have on maintenance and supply functions. Using pre-existing maintenance and supply data, a simulation model was developed to more accurately determine any maintenance and /or supply related cost benefits. The goal was to provide better accuracy on the associated costs and benefits of ARGCS technologies, thus enhancing the accuracy and merit of future BCAs. The only F/A-18 Weapons Replaceable Assemblies (WRA) that were analyzed during this research project were those that will be tested during the summer 2007 Advanced Concept Technology Demonstration (ACTD) at Lemoore Naval Air Station. Results of the simulation indicate there is an expected increase in operational availability and several cost savings associated with the implementation of ARGCS technologies.

THIS PAGE INTENTIONALLY LEFT BLANK

TABLE OF CONTENTS

THIS PAGE INTENTIONALLY LEFT BLANK

LIST OF FIGURES

THIS PAGE INTENTIONALLY LEFT BLANK

LIST OF TABLES

THIS PAGE INTENTIONALLY LEFT BLANK

LIST OF ABBREVIATIONS AND ACRONYMS

ACTD	Advanced Concept Technical Demonstration
ADSR	ARGCS Distance Support and Response
AIMD	Aircraft Intermediate Maintenance Department
ARGCS	Agile Rapid Global Combat Support
AS&C	Advanced Systems and Concepts
ATE	Automated Test Equipment
ATS	Automated Test System
BCA	Business Case Analysis
BCM	Beyond Capability of Maintenance
FCC	Flight Control Computer
FMC	Fully Mission Capable
FRC	Fleet Readiness Center
I-Level	Intermediate Level
MTBF	Mean Time Between Failures
NAS	Naval Air Station
NAVAIR	Naval Air Systems Command
NMC	Non-Mission Capable
PACOM	Pacific Command
PMA	Program Management Activity
TPS	Test Program Set
TTR	Time to Repair
WRA	Weapons Replaceable Assembly

THIS PAGE INTENTIONALLY LEFT BLANK

ACKNOWLEDGMENTS

a. USD (AS&C)

b. PACOM

c. NAVAIR PMA-265

d. The section of the analysis is derived in concept from the Department of Defense Automatic Test Systems Executive Directorate's 2005 DoD ATS Selection Process Guide.

e. Northrop Grumman

THIS PAGE INTENTIONALLY LEFT BLANK

I. INTRODUCTION

A. PURPOSE

The objective of this project was to identify and more accurately predict the maintenance and supply chain costs and savings related to the Agile Rapid Global Combat Support (ARGCS) system. The project focused on a portion of the ARGCS business case analysis (BCA) model developed by CDR David Crosby. CDR Crosby's BCA model listed various potential savings associated with the ARGCS system that were difficult to quantify during his initial BCA research. The focus of this research was to determine the potential benefits, and/or cost savings that ARGCS may have on maintenance and supply functions. Using pre-existing maintenance and supply data, a simulation model was developed to more accurately determine any maintenance and supply related cost benefits. The goal was to provide better accuracy on the associated costs and benefits of the ARGCS system, thus enhancing the accuracy and merit of future BCA analysis. The only F/A-18 Weapons Replaceable Assemblies (WRA) that were analyzed during this research project were those that will be tested during the summer 2007 Advanced Concept Technology Demonstration (ACTD) at Lemoore Naval Air Station.

B. RESEARCH QUESTIONS

The ARGCS Business Case Analysis presently being produced by the Naval Postgraduate School identifies many costs and benefits of this new system that are difficult to quantify. The following questions are the focus of this research:

1. What are the cost savings associated with faster Test Program Set (TPS) run times with Smart TPS and parallel testing incorporated?
2. What Operational/Intermediate Level (O/I-Level) savings are associated with more accurate/timely troubleshooting?
3. What spares cost savings will be realized as a result of lower Time to Repair (TTR)?
4. What cost savings will result from reduced transportation of WRA's sent off site?

5. Does ARGCS increase repair capability (I-level) of already repairable WRA's? If so, how will this affect supply chain outcomes like cost and readiness?

6. What cost savings can be realized from identification of WRA's with higher than average fail rates, a.k.a. "Bad Actors?"

7. How many Maintenance Man-hours can be saved due to faster test times?

C. METHODOLOGY

This research project modeled the current F/A-18 repairable supply chain at the Fleet Readiness Center (FRC) level using Arena Simulation Modeling software to predict potential readiness benefits of ARGCS. The potential readiness benefits researched included increased mission capable rates (operational availability), labor cost savings, repair cost savings, and reduced spare levels. Information gathered from various historical references was utilized to build the model. The intent was to assume as little as possible about the process. Although many historical facts were gathered, the model still contains assumptions that limit its ability to predict the benefits of implementing the ARGCS with 100% accuracy. Furthermore, due to the extreme difficulty of simulating every possible maintenance action (both scheduled and unscheduled) for the large number of aircraft supported by an FRC, the simulation only looks at the unscheduled maintenance aspect of four WRAs through the F/A-18 repair cycle. Specifically the model simulates the repair cycle of the F/A-18 APG-65 Radar Target Data Processor, Receiver Exciter, Antenna, and the CP1330/ASW-44 Roll Pitch Yaw Computer (a.k.a. Flight Control Computer, FCC).

II. BACKGROUND

A. DESCRIPTION OF ARGCS

ARGCS is an ACTD research program which seeks to incorporate new technologies in the areas of diagnostics, testing and repair for weapon systems, and inter-service test software interoperability. "ACTDs are designed to allow users to gain an understanding of potential new capabilities for which there is no user experience base" and in the end provide the Warfighter the opportunity to "make an assessment of the military utility of the proposed capability."[1] Within this framework, ARGCS is being developed to provide greater efficiency and effectiveness in the test, repair and maintenance functions of the services.

Proponents of ARGCS argue that existing systems are antiquated, cumbersome, inflexible, and lack the interoperability required to promote efficiencies of scale and scope. Current systems are stove-piped and fail to promote common functionality over a cross section of users. These structural inefficiencies entail a larger proliferation of automated test equipment (ATE) than might be achievable by incorporating current technologies that can not only increase efficiencies, but allow for an architecture that will be able to incorporate future technologies.

As proposed, the ARGCS technologies will integrate Automatic Test System (ATS) hardware and software with a net-centric support system designed to improve electronic systems maintenance. The ARGCS concept will combine building block, state-of-the-art instrumentation with an open system architecture that will be compatible with legacy TPSs currently in use by the Services and potentially prove the concept of interservice test software interoperability. The support system, called the ARGCS Distance Support and Response (ADSR) system, will facilitate data sharing and improve diagnostic capabilities.

[1] Office of Secretary of Defense, "Advanced Systems and Concepts, Advanced Concepts/ Joint Capabilities Technical Demonstrations" website, http://www.acq.osd.mil/actd/intro.htm, accessed October 13, 2006.

The TPSs are combinations of hardware and software that have been created to test specific equipment using specific ATSs. In the current state, the different services use different ATSs. The ARGCS system will use interface adaptors to connect legacy TPSs to a common test interface on its ATS. This has the potential to allow for a common ATS for all Services without re-engineering existing TPSs.

In concept, the ARGCS Distance Support and Response (ADSR) will work with ATSs and other diagnostic equipment by using internet connectivity to populate a central database providing more information to maintenance personnel in the field and more precise unit testing capabilities. The ADSR architecture allows data to be collected at all levels of maintenance (Operational, Intermediate, and Depot) to perform more exacting maintenance at each activity. ARGCS proponents claim that the technology will allow the reuse of weapon system-level built-in-test information and historical system failure data to continually improve the quality of the diagnostics. Fault event/diagnostic data along with maintainer assessments will be collected and automatically evaluated to develop guidance and recommendations to subsequent similar events. Conceptually, the architecture will also provide the capability for remote Subject Matter Experts to assist on-scene maintenance personnel.[2]

[2] *Business Case Analysis: Agile Rapid Global Combat Support*. MBA Professional Report. Naval Postgraduate School. CDR David Crosby, 2006.

III. SIMULATION MODEL DEVELOPMENT

A. MODEL DESCRIPTION, ASSUMPTIONS, AND LIMITATIONS

The model developed for this research project attempted to simulate a repair cycle based on the Fleet Readiness Center (FRC) concept. The FRC concept is the Navy's new "center of excellence" concept in which I-level repair is centralized to one of six locations based on repair expertise. This allows I-level technicians to work side-by-side with local "In Service Repair Depot" artisans in the AIMD facility, thereby reducing repair cycle times and inventory, while increasing "Ready-for-Issue" (RFI) rates. NAS Lemoore is one of the designated FRCs for the WRAs (Radar & RPYC) applicable to this project. In other words, NAS Lemoore will repair not only the WRAs from its location, but will also repair WRAs from NAS Fort Worth and NAS Fallon. Based on the approximate number of F/A-18 squadrons (approx. 12) from the three different locations, the FRC West at Lemoore AIMD will support a WRA (Radar/RPYC) inventory for roughly 144 aircraft. This is the number of aircraft used for the simulation. Additionally, the model accounts for unscheduled maintenance only. It was proven through many trials that individually scheduling all 144 aircraft to account for the numerous scheduled downtimes a typical F/A-18 goes through each year was futile.

With the use of Arena software, this project attempted an "As-Is" simulation of the existing repair cycle of F/A-18 aircraft. In theory, it would be possible to change various factors within the model that are influenced by the ARGCS system and then observe how these factors affect the average number of FMC aircraft, operational availability, operational level repair costs, intermediate level labor costs, average Depot level repair costs, and associated transportation costs. All of these are questions requiring answers for the ARGCS Business Case Analysis being conducted by the Naval Postgraduate School. Figure 1 is a graphical representation of the overall Arena Simulation Model.

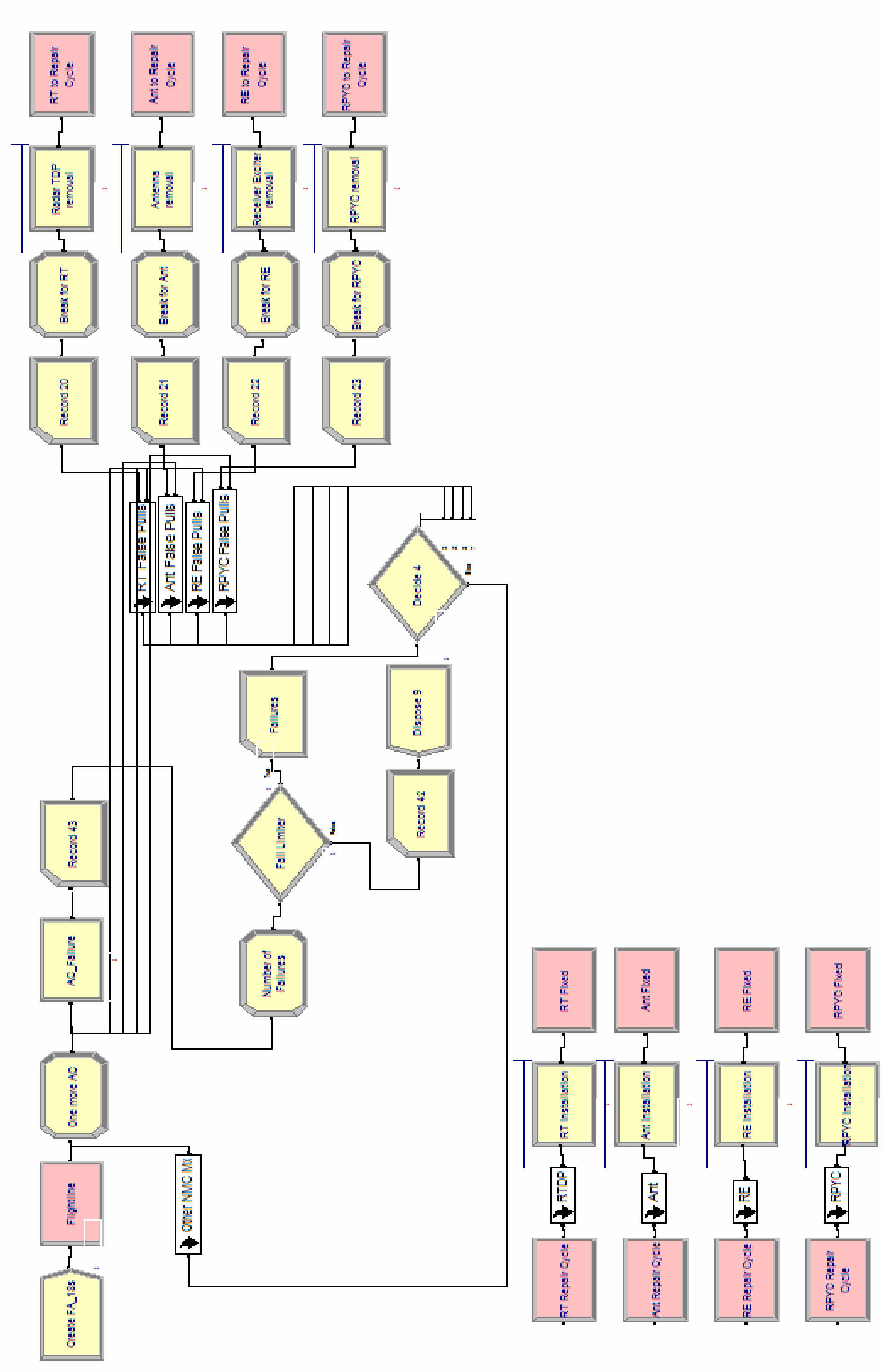

Figure 1. F/A-18 Repair Cycle Simulation Model

Because of the many factors involved in the repair process, and the lack of some data, certain assumptions had to be made in order to build the simulation model. These assumptions are highlighted and explained throughout this chapter and are important to keep in mind when using the results of the simulation for the ARGCS Business Case Analysis.

The basic building blocks for Arena are called modules, which define the process being simulated. Figure 2 represents the first three modules of the simulation. The first module, Create FA_18s, is the "birth" node for arrival of entities to the model's boundary.[3] By creating the entities, in this case aircraft, the model can now simulate whatever process is built for it. The next module, Flightline, simply provides an avenue for entities to return later once they've been through one of the many possible lines of the model. This module has no effect on the entities. The last module in Figure 2, One more AC, adds two variables to the simulation. The first creates a Fully Mission Capable (FMC) aircraft and the other calculates operational availability.

Figure 2. Create Module/FMC and Op Avail Calculation

The next section of the model, shown in Figure 3, establishes the Failure Rate of the aircraft entities. The first module in this section, AC_Failure, causes the aircraft entities to delay for a specific time period. Due to the fact that the model is based on time, and most components on an aircraft follow an exponential failure distribution, an exponential distribution was used to represent the MTBF of each aircraft. The aircraft MTBF assumed for the simulation was 5.1 hours. This number was chosen based on discussions with Naval personnel and the project team's personal experience of flight line operations. Assuming each aircraft flies an average of 10 hours per week (3 to 4 sorties), and there are 168 hours in a week, each aircraft flies 1.4 hours per day (10 hours / 7

[3] W. David Skelton, Randall P. Sadowski, David T. Sturrock, *Simulation with Arena*, Third Edition (New York, NY: McGraw-Hill, 2004), p. 57.

days). To adjust for the continuous clock time of the simulation model, the aircraft MTBF was divided by 0.06 (10/168) which resulted in an MTBF of 85 hours for the simulation. This equates to an aircraft failing once every 2-3 flights based on the assumption that flights generally last 1.5 to 3 hours (typical for fighter aircraft The 85 hours accounts for both ground and flying time. This operational tempo could be increased or decreased by changing the numerator in the MTBF equation and changing the model accordingly. It is reasonable to assume that any change in the operational tempo would have some effect on the entire model; however, the operational tempo was not changed during this research due to time constraints.

The second module, Record 43, simply counts the failures as they are released from the previous module. This module is not necessary for the model to work, but makes it easier to interpret the data. This is true for all "Record" modules in the simulation.

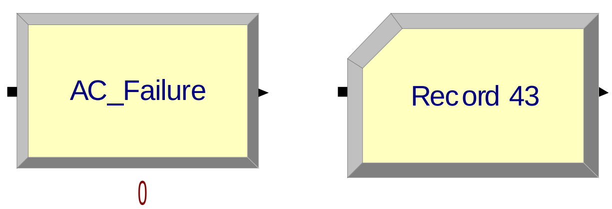

Figure 3. AC Failure/Record

The first module in Figure 4, Number of Failures, establishes a variable to be used in a decision made in the next module, Fail Limiter. The Fail Limiter module makes a decision to limit the number of failures allowed to proceed through the simulation. After several runs, the simulation model revealed that aircraft failures increased when repair cycle times were reduced. This anomaly was caused by the aircraft and WRAs being repaired faster, which enabled them to enter the Flightline module at a faster rate and in turn enter the AC_Failure module more often. Realistically this would not happen. In the aircraft operations world, there is a familiar saying, "Plan what you fly, and fly what you plan." Aircraft do not break more just because they are repaired faster. In addition, they are not normally flown more just because there are a higher number of average FMC aircraft available. This increased failure rate occurs in our model because of our

modeling decision to model total aircraft hours. Hence greater availability of aircraft translates into a greater number of aircraft failures. The decision to model total aircraft hours was made for parsimony, and to keep the model tractable. As a consequence however, we needed some method to keep the failure rate from increasing so accurate costs savings could be calculated. To limit these additional failures, the aforementioned Fail Limiter was used to prohibit more than the preset number of failures to continue through the simulation. The failure limit is based on the minimum average number of failures generated by the base scenario (10,310 failures). While this 'failure limit' approach does not affect the average failure rate, it will affect the distribution of failures. In other words the failures will occur early in the simulation and then cease later in the simulation. We were unsure exactly how much this skewing impacted operational availability, so to negate any impact on operational availability a terminating condition was established to provide a more accurate result. This fail limiter and terminating condition are discussed in greater detail in the model results section. Here, we simply note that the need to incorporate this module means our operational availability results are an approximation, and that our model should be considered a heuristic. While we have incorporated essential variables in a way that is satisfactory for the purposes and limited scope of this report, the numerical results for operational availability should not be considered exact. The final module in this section, Failures, is another record module for counting purposes.

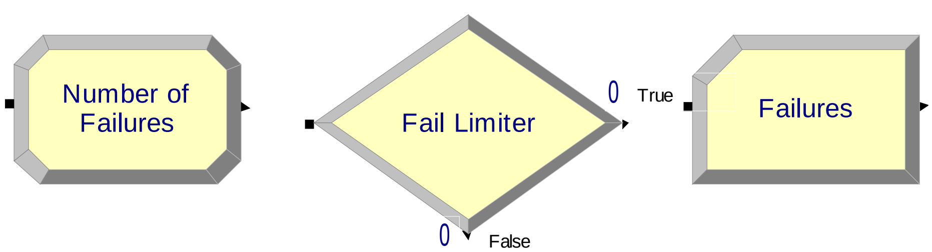

Figure 4. Fail Limit Section

The module, Decide 4, in Figure 5 is a crucial element of this simulation. Since there are pre-identified WRAs the ACTD will run during future tests of the ARGCS, a percentage of total failures was established. Based on the average number of annual

failures of each WRA[4], a percentage of aircraft failures take a path to one of four WRA repair cycles. There are no distinctions of individual WRA failures, only that each failure routes the aircraft entity to the appropriate repair cycle based on the aforementioned failure rate.

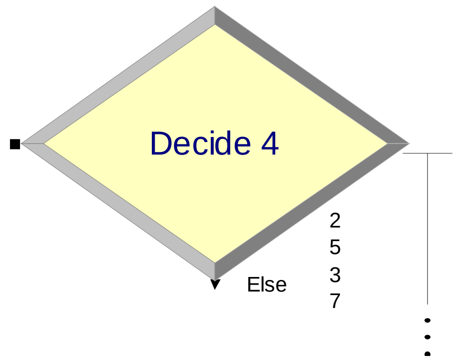

Figure 5. What Broke? Decision

The failures that do not enter one of the WRA repair cycles are directed to the Other NMC Mx module (Figure 6), where they are delayed for an assumed exponential delay of 10 hours to account for all other unscheduled maintenance actions. This delay is very rough, but is based on personal experience. For example, some flight line repairs can take as little as 30 minutes, while others may take several days to complete. The numerous failures possible outside the scope of the WRAs studied in this project could not be fine tuned to a completely accurate number. However, with over 25 years of flight line experience, the project team members agreed that 10 hours was a fairly reasonable number. Additionally, we felt as long this repair time stayed constant throughout the different scenarios, model results could be compared.

Figure 6. Other NMC Mx Module

[4] NAVAIR Informational CDROM, APG-65 Radar Fleet Support Team & Wyle Laboratories, Inc. Aerospace Group Integrated Logistics Supportability Team, October 2006.

A total of 17% of aircraft failures enter one of the four WRA repair cycles, each based on historical repair data.[5] Table 1 represents the percentage of total failures routed to the applicable WRAs and the resulting base model failures. The percentages chosen were based on recreating the actual number of average failures over the last 5 years. For example, the average number of Radar Target Data Processors (RTDP) sent for repair was 202.8 RTDPs per year.[6] In order to achieve this number of failures in the model results, the desired number of failures was divided into the total number of failures (202.8/10,310) resulting in 2% of total failures. The same method was used to determine the percentage of total failures for each WRA. The average number of failures per year varies slightly due to time distributions within the model as well as averaging of the replication results.

WRA	Failure Percentage	Average Failures/Year
RTDP	2%	209
Ant	5%	512
RE	3%	312
RPYC	7%	722

Table 1. WRA Failure Percentage

The model splits in five possible paths after the Decide 4 module. As previously stated, this module routes a predetermined percentage of failures to the maintenance cycle for the WRAs being analyzed. All other failures proceed to the Other NMC Mx Submodel seen in Figure 6. This submodel includes a module which reduces the number of FMC aircraft and recalculates operational availability to account for an aircraft that is now Non-Mission Capable (NMC). The second module located in this submodel, delays the aircraft using an exponential distribution. As previously mentioned, this delay is to account for the time required to repair all other NMC conditions.

---

[5] NAVAIR Informational CDROM, APG-65 Radar Fleet Support Team & Wyle Laboratories, Inc. Aerospace Group Integrated Logistics Supportability Team, October 2006.

[6] NAVAIR Informational CDROM, APG-65 Radar Fleet Support Team, October 2006.

The failures that are routed to one of the WRA maintenance cycles must first pass through the submodels seen in Figure 7. Each submodel contains a decide module able to reduce the number of failures entering the associated maintenance cycle to simulate a reduction in false pulls of that WRA.

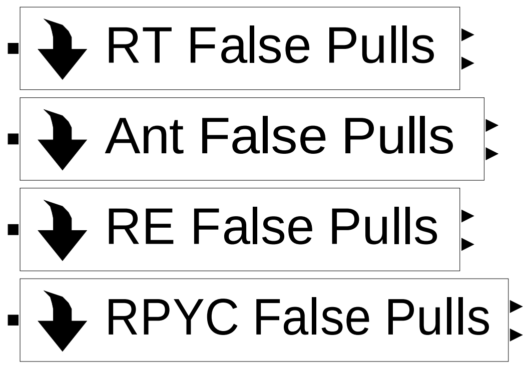

Figure 7. False Pull Submodels

A false pull is defined as a WRA that was removed to correct an aircraft failure, but actually wasn't the cause of the failure. To determine the false pull rate of each WRA, the number of "no fault found" actions at the I-level was compared to total failures for the applicable WRA at the O-level (Table 2)[7]. A record module was also used to count the number of false pulls to assist in interpreting the simulation results. These false pulls are routed to the AC_Failures module to await another failure.

WRA	False Pull Rate
RTDP	8%
Ant	5%
RE	7%
RPYC	8%

Table 2. WRA False Pull Rates

The next few modules, Figure 8, represent the start of the maintenance process for the failed aircraft. Although each WRA maintenance cycle is built identically, the Radar TDP is represented in Figure 8. The Record 20 module simply counts the number of entities entering each maintenance path.

[7] NAVAIR Informational CDROM, APG-65 Radar Fleet Support Team & Wyle Laboratories, Inc. Aerospace Group Integrated Logistics Supportability Team, October 2006.

The next module, Break for RT, is used to reduce the FMC total by one and to recalculate operational availability. Next, the Radar TDP removal module is where the actual maintenance of the WRA starts. First, an O-level Sailor is assigned to accomplish the removal of the WRA from the aircraft. This seizure has an associated cost (repair cost)[8] representing half of the charge to the unit associated with ordering the part from supply (the remaining cost will be charged when the WRA is replaced). Each WRA repair process starts with removal and ends with installation of the replacement WRA. The time required to remove or install any WRA is based on many factors such as technician experience, location of the WRA, and environmental. Since these factors are very hard to predict, a triangular delay distribution was assumed for repair and installation of WRAs using a minimum of .5 hours, a most likely delay of 1 hour, and a maximum delay of 1.5 hours per maintenance action. These delays are based on personal experience and actual technician estimates.

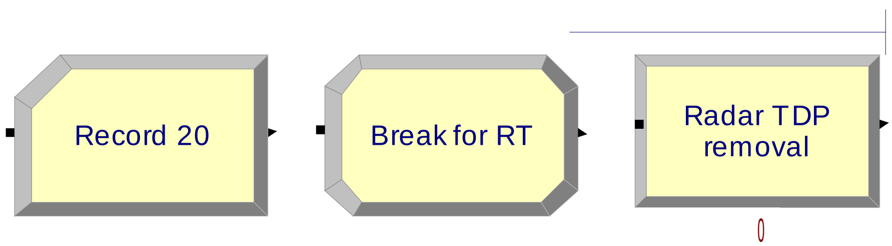

Figure 8. Introduction into Maintenance Cycle

The next submodel, Figure 9, includes several modules that separate the components from the aircraft and bring the aircraft back together with a Ready-for-Issue (RFI) WRA. In addition to the aforementioned processes, the WRA enters its repair cycle in this submodel.

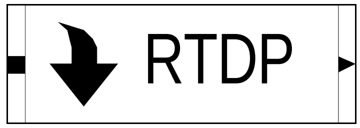

Figure 9. Maintenance Cycle Submodel

[8] Navy Inventory Control Point Asset Visibility System, https://www.navsup.navy.mil, accessed August 2006.

First, an explanation of the modules in Figure 10 is necessary to understand how the aircraft gets repaired without waiting for the WRA to go through the repair cycle. The Separate module splits the aircraft entity into two parts. By doing this, the simulation allows the aircraft entity to proceed to two different paths.

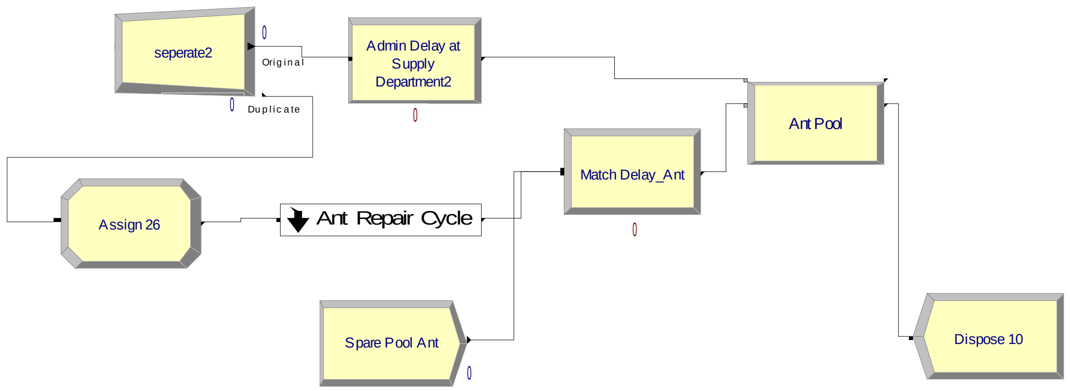

Figure 10. Separating WRA from Aircraft

The original aircraft entity proceeds to a delay module, Admin Delay at Supply Department. A triangular delay distribution was assumed for this module with a minimum of .5 hours, a most likely delay of 1 hour, and a maximum delay of 1.5 hours per supply action. This delay is based on project team personal experience. Then, the aircraft proceeds to the Pool module to receive a replacement WRA. That concludes the aircraft flow through this process.

The duplicate aircraft entity of the Separate module proceeds to an Assign module where it becomes the WRA entity that will enter the Repair Cycle submodel, which will be discussed later. Once the WRA exits the Repair Cycle submodel it proceeds to a Match Delay module. This module allows entities from the repair cycle and from the Spare Pool module to enter the Pool module together. There is no actual time delay, but this module is required for proper matching of aircraft and WRA entities at the Pool module.

The Spare Pool module is a create module used to introduce spares into the supply chain. The spare levels in the model are based on actual spare numbers with the exception of the RPYC spares. The number of RPYC spares was assumed based on

average annual failures seen at the NAS Lemoore AIMD. Since this model is based on 144 aircraft, not 438 (total F/A-18 inventory), the spare levels are a percentage of the actual levels. Table 3 identifies the number of spares used in this model, for record keeping purposes.[9]

WRA	# of Spares
RTDP	65
ANT	39
RE	120
RPYC	130

Table 3. Spare Levels

Once the aircraft entity has matched with a WRA entity there is now one entity created from the two. The aircraft and its new WRA proceed to the applicable Installation module, Figure 13. To eliminate the additional entity, a Dispose module is used to escort the additional entity out of the model.

The FRC Repair Cycle, Figure 11, is more complex than previous sections due to the detail required of the model pertaining to the I-level repair effort. Since proponents claim ARGCS will reduce several aspects of this repair cycle, the model includes enough detail to make the appropriate adjustments.

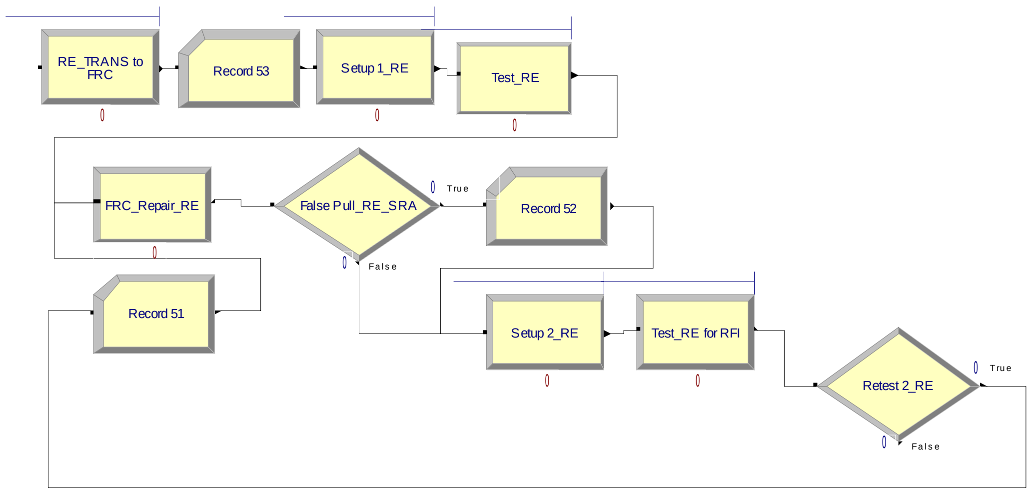

Figure 11. FRC Repair Cycle

[9] NAVAIR Informational CDROM, APG-65 Radar Fleet Support Team, October 2006.

The first module, TRANS to FRC, delays WRAs entering from Figure 10 to account for transportation and is followed by a Record module to count transportation events. All transportation modules assign a truck, and accordingly apply a usage cost per delay. Transportation of NAS Lemoore WRAs will take place locally, which essentially costs next to nothing and takes very little time. On the other hand, WRAs traveling to and from NAS Fort Worth, NAS Fallon, or Depot will have different delays at different rates due to the additional distance to transport. Since this rate information was not available, an assumed average transportation charge of $200 and a delay of 1-2 days distributed uniformly were used for all transportation events.

The Setup module assigns a Sailor to accomplish the appropriate setup required for the WRA entering the repair cycle. This setup time is different for each WRA. Once setup is complete, the WRA will proceed for testing.

The Test module then assigns a Sailor for an exponential delay based on applicable test times. Once a WRA enters its respective repair cycle, the model assumes delays based on historic information applicable to that particular WRA. Table 4 represents the type and associated delay associated with each WRA.[10] The repair delays in Table 4 were provided by Aerospace Group, Wyle Laboratories Inc. (G. Jacobson, personnel communication, August, 2006).

WRA	Set up Delay (Normal Dist)	Test Delay (Exponential)	Repair Delay (Exponential)
RTDP	.3 hours, std dev .1 hours	2 hours	5 hours
Ant	.3 hours, std dev .1 hours	1.5 hours	8 hours
RE	1.5 hours, std dev .25 hours	4.3 hours	9 hours
RPYC	.5 hour, std dev .1 hours	2.5 hours	2 hours

Table 4. I-Level Repair Cycle Delays

Once tested, the WRA proceeds to the FRC_Repair module where it seizes a Sailor for an exponential delay based on applicable repair times (Table 4). After repair the WRA proceeds to a second set of Setup and Test modules. These modules perform the same function as the modules preceding the FRC_Repair module.

[10] Steve J. Padilla, Principal Tech Support Engineer-Radar Field Engineering & Matthew R. Corney, Sr Customer Support Engineer-Field Engineering, NAS Lemoore, CA, interviewed October 2006.

Once RFI tested, the WRA proceeds to a decision module (Retest) to determine whether or not the WRA actually passed the RFI test. The retest percentage after each WRA has been tested for RFI is assumed at 20% to simulate 1 in 5 WRAs requiring further repair. This assumption is based on personal experience and discussions with technicians at NAS Lemoore. These retests are not a result of the inability to repair a WRA, but a failed repair attempt. Failures proceed back to the FRC_Repair module. Passes proceed to the decision module (BCM?) seen in Figure 12.

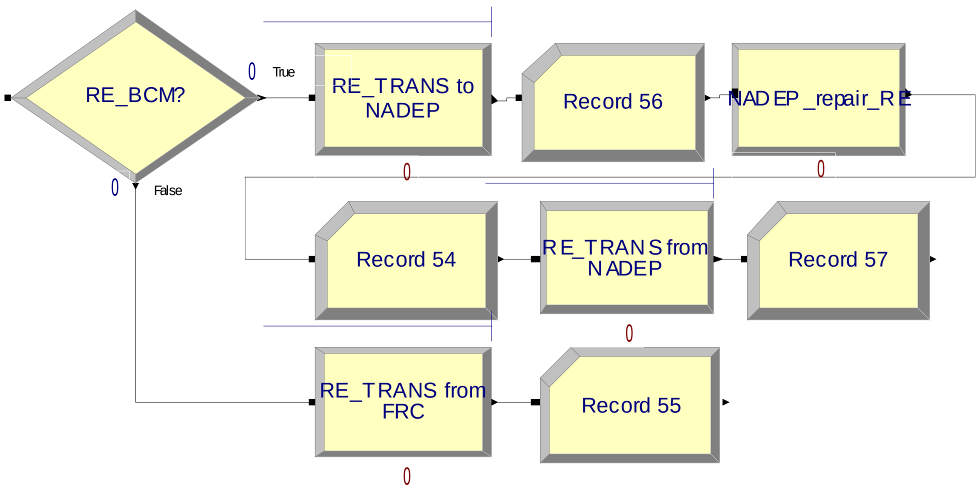

Figure 12. BCM/Depot Repair

If the WRA is determined to be Beyond the Capability of Maintenance (BCM), it will proceed for transportation to Depot level repair via the TRANS to NADEP module. Each WRA has an applicable BCM rate based on historical data. Table 5 displays the BCM rates that apply to each WRA.[11] A record module counts transportation of the WRA from the previous module.

WRA	BCM Rate	# to Depot (base Simulation)
RTDP	6%	11
Ant	5%	23
RE	7%	19
RPYC	9%	55

Table 5. BCM Rates

[11] NAVAIR Informational CDROM, APG-65 Radar Fleet Support Team & Wyle Laboratories, Inc. Aerospace Group Integrated Logistics Supportability Team, October 2006.

Once the WRA arrives to the depot (represented by the NADEP_repair module) it assigns a Depot level technician for an assumed exponential distribution delay of 10 days to account for the time taken to repair the WRA at depot. This assumption is based on discussion with technicians and personal experience. Unfortunately, after repeated requests, the average Depot repair cost of each WRA was not provided, so each event was assumed to cost $5,000. In the future, if this information is provided, it could easily be input into the model to more accurately predict actual depot maintenance costs.

Once repaired the WRA proceeds for transportation (TRANS from NADEP) and is routed to the Match Delay module seen in Figure 10. Those WRAs not considered BCM (i.e. actually repaired at the FRC) proceed to the TRANS from FRC module. From this module the WRA proceeds to the Match Delay module in Figure 10.

Finally, once the aircraft has received its replacement WRA, it proceeds to the Installation module, Figure 13, where it repeats the actions associated with the removal module earlier in the simulation. Since the removal and installation both charge half of the repair cost, the total repair cost associated with the applicable WRA is totaled. After the delay associated with this module, the aircraft proceeds to the Fixed routing module where it proceeds to the Flightline station module shown previously in Figure 2.

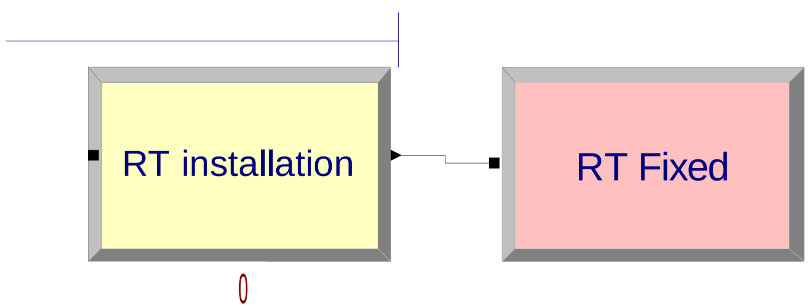

Figure 13. Install/Route Modules

IV. MODEL RESULTS AND ANALYSIS

A. BASE MODEL

The model was set up to simulate 40 replications lasting 360 days each The model was able to identify the average Operational Availability, number of FMC aircraft, number of breaks for each of the identified WRAs, and number of Depot repairs. In addition, associated costs such as average O-level repair cost (cost to the operational unit per WRA ordered), average I-level labor cost, average Depot repair cost, and average transportation costs associated with the repair cycle were identified.

As stated previously, the Base Model involved 144 aircraft that had an average of 85 hours between failures using an exponential distribution. Based on this failure rate, an average of 10,310 failures occurred every 360 day period. Of those 10,310 failures, 17% of these failures actually resulted in WRAs being tested. Table 6 identifies the results associated with the base model simulation.

Operational Availability	68%	Transportation Cost	$ 693,695.00
FMC A/C	98	I-Level Cost	$ 1,139,933.40
RT Breaks	209	O-Level RT	$ 8,055,162.50
Ant Breaks	512	O-Level Ant	$ 10,155,750.00
RE Breaks	312	O-Level RE	$ 8,418,600.00
RPYC Breaks	722	O-Level RPYC	$ 3,321,085.00
RT Depot Repairs	11	RT Depot Cost	$ 55,625.00
Ant Repairs	23	Ant Depot Cost	$ 119,125.00
RE Depot Repairs	19	RE Depot Cost	$ 99,250.00
RPYC Depot Repairs	55	RPYC Depot Cost	$ 284,875.00
		Total Repair Cycle Cost	**$ 32,343,100.90**

Table 6. Base Scenario Results

B. SCENARIO 1: FASTER TPS RUN TIMES

One of the claimed advantages of utilizing the ARGCS technology is faster TPS run times. In the first scenario, the test times for each WRA were reduced at various levels from 5%-50%. Before these results are discussed, an explanation of the model limitations concerning operational availability needs to be addressed.

In order to maintain the number of failures at a steady rate and compensate for the simulation anomaly discussed on page 8, the fail limiter was created. Unfortunately, the fail limiter introduced a problem in the operational availability calculation. Because the fail limiter did not allow any failures after the pre-determined limit was reached, the operational availability during the last portion of each replication went up to 100% (no aircraft failures), skewing the results higher than expected.

In order to reduce the impact the fail limiter had on operational availability, a terminating condition was created. The introduction of the terminating condition stopped the replication as soon as the fail limit was reached. However, due to the limited scope of this project, we were not able to conduct sensitivity analysis on the impact of the fail-limiter module or the terminating condition, and hence we cannot be certain exactly how much that approximation may have skewed the results. It may be that reducing TPS run times would have a greater or lesser impact on availability than our results indicate, and we cannot be precise in the impact of this factor vice other considerations (e.g., increased accuracy).

Operational availability is comprised of many different factors, one of which is scheduled maintenance. Based on project team experience, the typical squadron will have approximately 10% of its aircraft fleet undergoing some type of scheduled maintenance. This means that normally, the best operational availability a squadron could expect is approximately 90%. Scheduled maintenance was not a focus of our research so it was not included in the simulation model. To account for scheduled maintenance, the operational availability results produced by the simulation were multiplied by 90%. For example, if the simulation model results indicated operational availability was 80%, we adjusted that number downward to 72% by multiplying by 0.9.

Figure 14 demonstrates the effect reduced run times have on operational availability. As indicated, by reducing TPS run times by 50%, operational availability of the 144 aircraft in the simulation improved by 12% (68% to 80%).

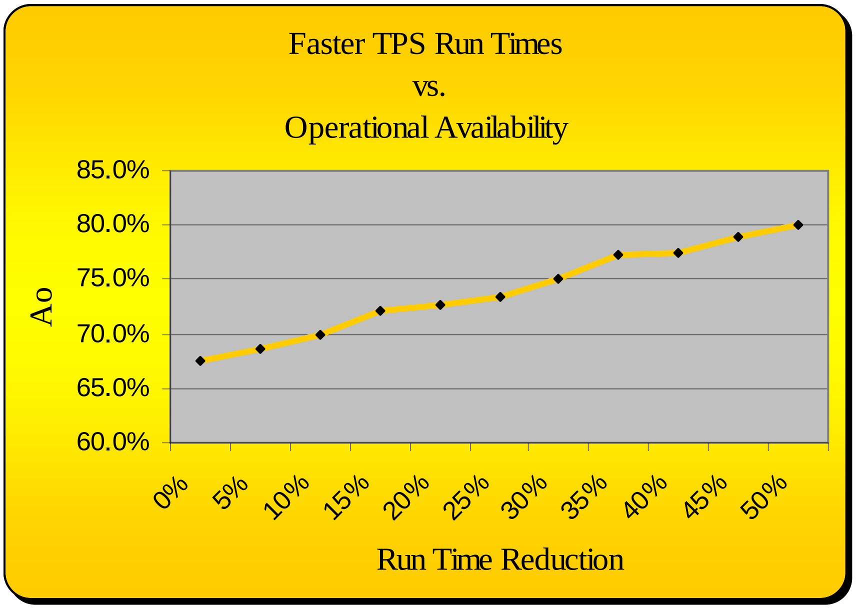

Figure 14. Effects of Faster TPS Run Times on Operational Availability

The costs associated with run times are limited to I-level labor ($50 per/hour) required to perform the WRA testing (G. Jacobson, personal communication, October 2006). The Maintenance Man-Hours (MMH) required are reduced as a result of faster run times. Table 7 displays reduced MMH numbers at different reduced TPS run times. Figure 15 demonstrates the effect the reduced run times have on the total cost of I-level labor.

Run Time Reduction	Total MMH	MMH saved	Percentage of Total MMH
0% (Base)	22803.99	0	0%
15%	22042.36	761.63	3%
30%	20558.66	2245.33	10%
45%	19148.44	3655.55	16%

Table 7. Reduction in MMH

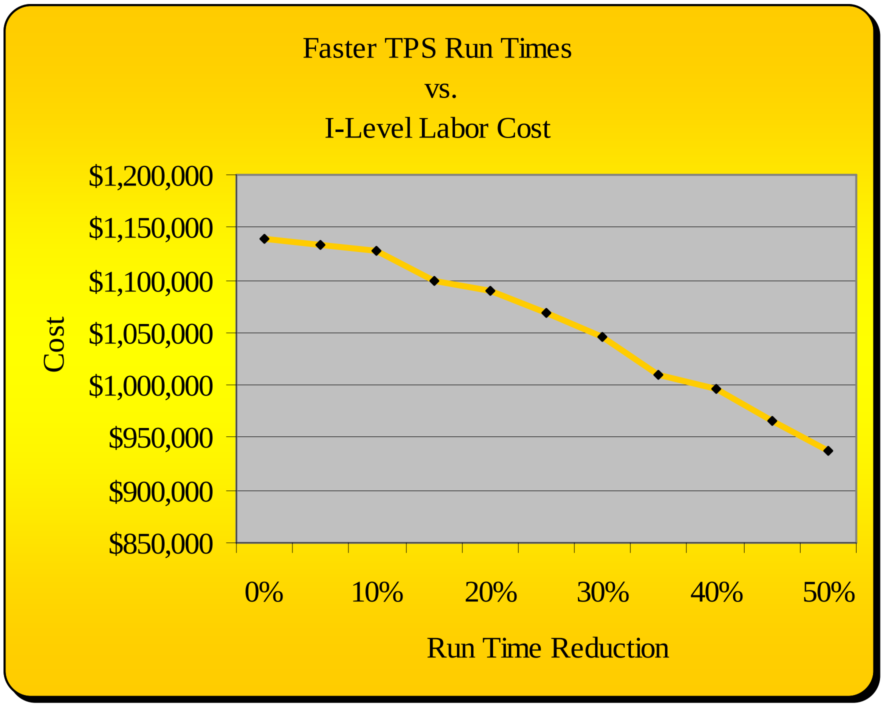

Figure 15. Effects of Faster TPS Run Times on I-Level Labor Cost

C. SCENARIO 2: INCREASED ACCURACY

ARGCS technologies claim to increase the accuracy as well as the timeliness of troubleshooting.[12] In order to assess these claims, model inputs were adjusted to reduce the number of WRA failures that actually enter the repair cycle. By doing this, the model simulates reductions in false pulls at the O-level. The cost savings associated with this adjustment are mostly realized at the O-level due to less WRA orders. Additionally, transportation costs associated with those orders are reduced. I-level labor cost savings are minimal due to the small percentage of WRAs that are actually false pulls at the O-level. It does, however, decrease the number of WRAs waiting in the queue for repair at the I-level, which may have some positive impact on inventory carrying cost. This potential impact is outside the scope of this research. Furthermore, this concentrates more I-level labor on WRAs that actually require a repair action, thus returning them to RFI condition at a faster rate. Table 8 represents the effect a 50% reduction in false pulls at the O-level has on the model and Table 9 represents the effect of a 100% reduction.

[12] Defense Information Systems Agency, *Agile Rapid Global Combat Support Advanced Concept Technology Demonstration Draft Integrated Assessment Plan*, July 2006.

Operational Availability	+ 4%
FMC A/C	+ 5
Transportation Cost Savings	$5,195.00
O-Level RT Savings	$436,975.00
O-Level ANT Savings	$123,500.00
O-Level RE Savings	$466,425.00
O-Level RPYC Savings	$111,550.00
Repair Cycle Cost Savings	**$1,143,645.00**

Table 8. 50% Reduction in False Pulls

Operational Availability	+ 6%
FMC A/C	+ 9
Transportation Cost Savings	$23,290.00
O-Level RT Savings	$885,500.00
O-Level ANT Savings	$408,250.00
O-Level RE Savings	$631,125.00
O-Level RPYC Savings	$274,505.00
Repair Cycle Cost Savings	**$2,222,670.00**

Table 9. 100% Reduction in False Pulls

Another approach is to reduce the percentage of retested WRAs. The model then sends fewer repaired WRAs back for repair at the applicable I-level repair station. In other words, the WRA is more likely to be successfully repaired the first time. The cost savings associated with this adjustment are realized mostly at the I-level of maintenance. Figure 16 represents the effects fewer additional repairs have on operational availability and Figure 17 the effects on I-level labor cost.

Figure 16. Effects of Less WRA Retests on Operational Availability

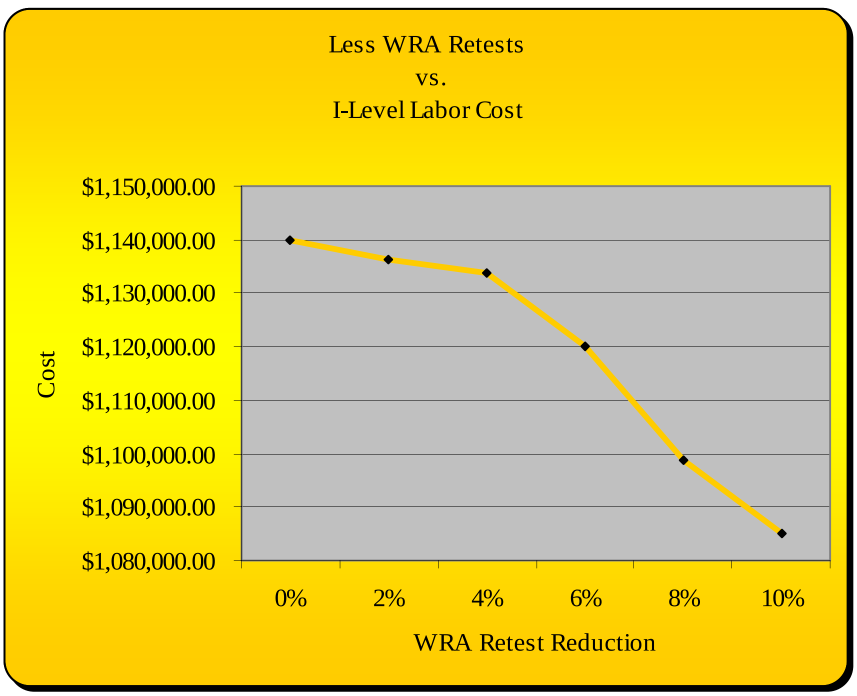

Figure 17. Effects of Less WRA Retests on I-Level Labor Cost

D. SCENARIO 3: SPARES REDUCTION

As the results in Scenario 1 indicate, operational availability increases as the TPS run times are reduced. In this scenario, spares are reduced along with the run times. Table 10 represents the reduced number of spares required to attain the base model operational availability. When spares were reduced to account for faster TPS run times, the model was run 5 years instead of one year as in the base scenario. The longer run time was required due to the longer term effects associated with spare usage. With the threshold for ARGCS faster run times at 15%, a 3% reduction in spares was realized. Assuming a 10% of standard price holding cost, a savings of $780,559.80 could result from this 15% reduction in test times. The model was also simulated with a spares reduction at 40% reduction in test times, but the results appeared to be unrealistic so an accurate prediction could not be made. With this in mind, it is realistic to predict a reduced level of spares beyond that predicted with the 15% run time reduction.

WRA	Spare Level	+/-	Standard Price	Savings of
RTDP	63	-2	$ 1,067,136	$ 2,134,272
Ant	37	-2	$ 444,893	$ 889,786
RE	116	-4	$ 1,047,905	$ 4,191,620
RPYC	126	-4	$ 147,480	$ 589,920
Total Standard Price Savings				$ 7,805,598
Annual Inventory Holding Cost Savings (Holding Cost =10%)				
				$780,559.80

Table 10. Spares Reduction

E. SCENARIO 4: INCREASED I-LEVEL REPAIR CAPABILITY

Although ARGCS advocates do not claim to affect the repair capability at the I-level of maintenance, it is nonetheless possible. By increasing the accuracy and timeliness of troubleshooting, it is likely less WRAs will be sent to the Depot for repair. This claim is based on the assumption that some of the BCM decisions consist of WRAs sent to Depot as a result of repair fatigue. The cost savings resulting from less WRAs repaired by the Depot are represented in Figure 18. Due to the fact that BCM rates are relatively low to begin with, the resulting savings are limited to average Depot repair costs and associated transportation costs. Additionally, it is likely a savings can be realized as a result of fewer spares required due to less WRAs going to Depot for repair.

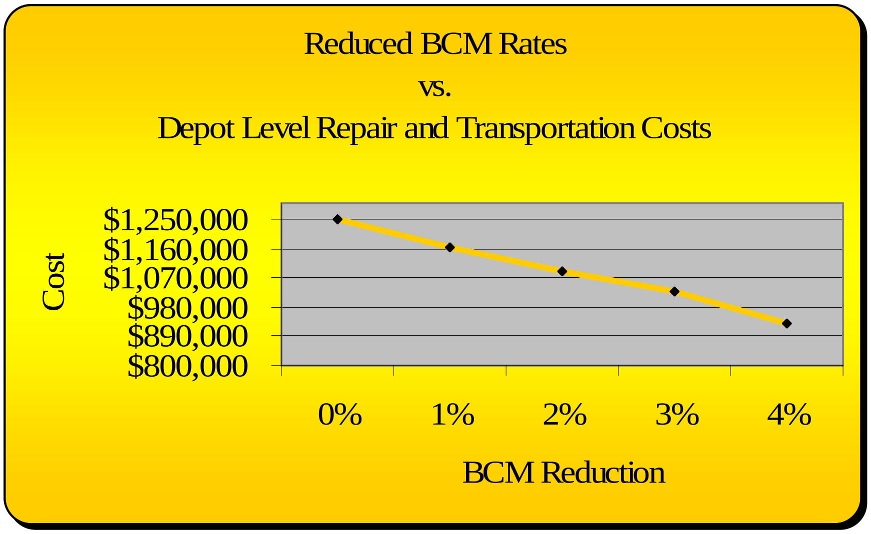

Figure 18. Effects of Reduced BCM Rates on Depot Repair/Trans Costs

F. BAD ACTOR DISCUSSION

Bad Actors are defined as those WRAs that exhibit very low hour failures and multiple failures within short periods of time. The Fleet Support Team at NAS North Island has identified all Radar WRAs that have exhibited 4 or more failures within a 21 month period. Contributing factors to Bad Actors prevalence include poor maintenance practices, TPS deficiencies, and design flaws. Due to its planned net-centric architecture, ARGCS technologies have the potential to improve visibility of bad actors by providing first hand failure information to the maintainer, TPS designers, and engineers, as well as allowing field level technicians real time access to subject matter experts. Unfortunately, the project team was unable to determine a way to incorporate Bad Actors into the simulation model. However, if the ADSR portion works as planned, significant savings could be attained by identifying, repairing, or eliminating Bad Actors from the repair cycle.

V. CONCLUSIONS

As the Arena model results indicate, the greatest cost savings comes from decreasing the number of WRAs entering the repair cycle. The reason for this is simple, when a WRA is pulled from an aircraft and inserted into the repair cycle, O-level maintenance is immediately charged a predetermined repair cost whether or not the WRA requires repair or not. This repair cost is usually significant. According to the Navy Inventory Control Point Asset Visibility System in July 2006, the standard price for a Radar Receiver Exciter is $1,047,905 and the repair price is $27,374.[13]

As noted above, the limited scope of our project necessitated the use of a heuristic to limit failure rates. However, we see no reason why this heuristic would have skewed results so that decreasing the number of WRAs from entering the repair cycle would look exceptionally attractive. We have not conducted sensitivity analysis on this point and thus we are not sure about the quality of our approximation. Hence, interpretation of our numerical results must be done with caution.

The key to reducing the logistics footprint and associated repair costs is keeping the WRA from entering the repair cycle in the first place. There are two ways to accomplish this. The first option is to reengineer the WRA to increase its inherent reliability and increase its MTBF. Unfortunately, this is almost impossible to do without spending considerable time and money. The second, (probably) more cost effective way is to improve troubleshooting techniques to reduce false pulls at the O-level and improve maintenance quality at the I-level.

According to a recent study by the FCC Process Enhancement Team (PET) at Naval Air Station North Island, the FCC is often replaced at the O-level as a first step to troubleshooting any flight control system failure. It is considered standard practice by many O-level activities, regardless of failure indication or A1-F18AC-570 troubleshooting directions to begin the maintenance action by replacing an FCC. On the

[13] Navy Inventory Control Point Asset Visibility System, https://www.navsup.navy.mil, accessed August 2006.

occasional difficult flight system failure such as an intermittent aircraft wiring problem, multiple good FCC's are removed before the actual aircraft problem is resolved.[14] ARGCS is envisioned to improve O-level troubleshooting techniques through the use of an O-level interface. Exactly how much the tester will improve troubleshooting techniques is unknown, but the result of the simulation model indicates a 50% reduction in false pulls will save over $1.1M annually (Table 7). More than $2M annual savings are realized if 100% of false pulls are eliminated (Table 8).

The model predicted a 3% reduction in spares required to maintain the base model operational availability when TPS run times were reduced by 15%. Since, the spares already exist there are no savings due to buying less, but if holding costs are calculated as a percentage of WRA standard price, carrying less spares through attrition can be realized (Table 8). On the other hand, at a 40% reduction in TPS run times the spares reduction was over 50%, which is an unrealistic expectation in the opinion of the project team.

Ultimately, there are several cost savings involved with the thresholds and objectives of the ARGCS system. Faster TPS run times would have an immediate impact. However, the database that makes ARGCS capable of reducing false pulls and/or increasing the accuracy of troubleshooting must be populated with accurate data, and populating the database will not be instantaneous. It will likely take several months or perhaps years to adequately populate for increased maintenance effectiveness. If and when the Services can ensure accurate maintenance data collection at the different levels of maintenance, the true benefits of ARGCS could be realized.

[14] Mary Schmidt, *FCC PET Problems Prioritized By Cost*, Personal memo provided by William J. Greer, NAVAIRDEPOT 334. September 2006.

LIST OF REFERENCES

Corney, Matthew R. Senior Customer Support Engineer-Field Engineering. NAS Lemoore, CA. Interviewed October 2006.

Crosby, David. *Business Case Analysis: Agile Rapid Global Combat Support*. MBA Professional Report. Naval Postgraduate School. Monterey, CA. June 2006.

Defense Information Systems Agency. *Agile Rapid Global Combat Support Advanced Concept Technology Demonstration Draft Integrated Assessment Plan*. Fort Huachuca, AZ: July 2006.

Kelton, W. David, Sadowski, Randall P, Sturrock, David T. *Simulation with Arena*, Third Edition. New York, NY: McGraw-Hill, 2004.

NAVAIR Informational CDROM. APG-65 Radar Fleet Support Team. October 2006.

NAVAIR Informational CDROM. Wyle Laboratories, Inc. Aerospace Group Integrated Logistics Supportability Team. October 2006.

Navy Inventory Control Point Asset Visibility System. Web site, https://www.navsup.navy.mil. Accessed August 2006.

Office of Secretary of Defense, "Advanced Systems and Concepts, Advanced Concepts/ Joint Capabilities Technical Demonstrations," Web site, http://www.acq.osd.mil/actd/intro.htm. Accessed October 2006.

Padilla, Steve J. Principal Tech Support Engineer-Radar Field Engineering. NAS Lemoore, CA. Interviewed October 2006.

Schmidt, Mary. *FCC PET Problems Prioritized By Cost*. Personal memo provided by William J. Greer. NAVAIRDEPOT 334. September 2006.

THIS PAGE INTENTIONALLY LEFT BLANK

INITIAL DISTRIBUTION LIST

1. Defense Technical Information Center
   Ft. Belvoir, Virginia

2. Dudley Knox Library
   Naval Postgraduate School
   Monterey, California

3. Air Force Institute of Technology
   Wright-Patterson AFB, Ohio